Technical Report No. 497

A CROSS-CULTURAL INVESTIGATION OF CHILDREN'S CONCEPTIONS ABOUT THE EARTH, THE SUN AND THE MOON: GREEK AND AMERICAN DATA

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Abstract

In this report, we present the results of a cross-cultural study on children's knowledge about the shape, gravity, movement, and location of the earth and about the day/night cycle. The subjects of the study were elementary school students from Greece (N = 90) and the United States (N = 60). The results of the study showed that the children in both samples constructed similar initial concepts about the earth and went through similar steps in the process of changing these concepts to make them conform to the currently accepted scientific notions. Both the Greek and the American children conceptualized the earth as flat and stationary and thought it was located in the middle of the solar system. They also thought that things fall down, not toward the center of the spherical earth, and that the day/night cycle is caused by the movement of the sun and the moon. In the process of changing these concepts, the Greek and the American children formed similar misconceptions.

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Misconceptions in Science

One of the most interesting results of research in cognitive science and science education during the last ten years has been the realization that students often construct powerful misconceptions of science concepts (e.g., Clement, 1982; diSessa, 1982; Driver & Easley, 1978; McCloskey, 1983; Osborne & Wittrock, 1983; Viennot, 1979). For example, in the area of mechanics, some students think that a pellet impelled through a curved tube would continue in a curved path when it emerges from the tube (Caramazza, McCloskey, & Green, 1981). Other students develop a theory that a moving body has a force in it, and that the movement of the object is caused by that force (e.g., Osborne, 1984). In the area of light, most students believe that their eyes perceive objects directly, and that color is a property of the objects themselves (Anderson & Smith, 1986). Some students of electricity believe that a switch is like the trigger of a gun; it sends an impulse to a battery to trigger current flow from the battery to a light bulb (Collins & Stevens, 1984). Finally, in the area of astronomy, Piaget (1929) reports the case of a child who had developed the view that America was a flat piece of land located under Europe, and that at night the sun dropped through the European layer and illuminated the lower American layer!

Misconceptions may arise for several reasons. Concepts such as force or light may be misunderstood because they are extremely complex or abstract. Misconceptions can also be created in situations where the scientific explanation of a phenomenon contradicts the initial or naive concepts students have constructed on the basis of their everyday experience. Our research has focused primarily on this latter type of misconception.

Naive Concepts and the Process of Knowledge Acquisition

In our studies of knowledge acquisition in astronomy, we have identified a number of misconceptions that elementary school children in the United States have regarding the shape of the earth (e.g., Vosniadou, 1987, 1988; Vosniadou & Brewer, 1989). On the basis of this research we have come to the conclusion that children form misconceptions of the earth's shape because they find it very difficult to give up the idea that the earth is flat. All the misconceptions we have identified succeed in reconciling the phenomenal experience of a flat earth with the information coming from adults that the earth is a sphere. For instance some children believe that the earth is round like a disc rather than round like a sphere. By thinking of the earth as a disc, children succeed in reconciling the idea of flatness with the idea of roundness because a disc is both round and flat at the same time. Other children reconcile the idea of flatness with the idea of roundness by believing that there are two earths; a round one, which is a planet up in the sky, and a flat one on which we live.

The presence of these misconceptions reveals that children are not "blank slates" with respect to the earth's shape when they receive the information that the earth is a sphere, but that they have constructed an initial, naive concept of the earth according to which the earth is flat. This initial concept must be difficult to give up; otherwise children would have readily replaced it with a sphere concept instead of forming a misconception. More direct confirmation of the hypothesis that children start by forming an initial naive concept of a flat earth has been obtained from our studies of preschool children (Vosniadou & Brewer, in preparation).

We believe that initial concepts represent inferences or hypotheses about the observed world constructed by individuals on the basis of their everyday experience. These concepts are characterized by the fact that they require as little deviation from the world as phenomenally experienced as possible. These

concepts change as children are exposed to the dominant theories held by adults within a given culture. In some cases, this change involves replacing the initial concept with a culture-specific concept that appears to deviate from the world as phenomenally experienced. In these cases, the process of change is usually a long and difficult one and one that has the potential of giving rise to misconceptions. We think that many of the misconceptions uncovered by the science education research can be seen as resulting from children's attempts to assimilate the culture-specific theories to their initial concepts during the knowledge acquisition process, and for that reason we prefer to call them "assimilatory concepts" rather than misconceptions (see Vosniadou & Brewer, 1989, for a more extensive discussion of these issues).

Implications for Cross-Cultural Research

The realization that children construct initial naive concepts that are based on their everyday experience raises important questions about the knowledge acquisition process. How are such initial concepts acquired, how do they become restructured, and how do they influence further learning in a domain? In addition, the initial concept hypothesis has interesting implications for cross-cultural research. If initial concepts result mainly from an interaction of the human perceptual/cognitive system with information coming from the observed world (before the children are exposed to culture-specific information), one should expect that these concepts should be universal because the human/cognitive system and many aspects of the observed world are universal. In other words, one should expect young children to construct similar sets of initial concepts about the physical world regardless of the particular cultures in which they grow up.

If children are exposed to different kinds of culture-specific information as they grow up, they will modify their initial concepts in different ways to make them more and more consistent with the information they receive. In some cases, however, local culture-specific views have been replaced by scientific explanations that cross cultural borders. Consequently, many children end up receiving similar kinds of information from their culture regardless of the particular country in which they grow up. In these cases, if our analysis of the genesis of misconceptions is correct, one would expect to find not only universal initial concepts but also universal assimilatory concepts or misconceptions.

In this report, we test some of these hypotheses in a cross-cultural investigation of the concepts of the shape, gravity, location, movement of the earth, and of the phenomenon of the day/night cycle in elementary school children from Greece and from the United States.

Knowledge Acquisition in Astronomy

Although our experiential knowledge about the shape, movement, and location of the earth may not be as rich and direct as knowledge about the physical objects on the earth, it is nevertheless enough to create certain strong beliefs. Thus, we hypothesized that the process of knowledge acquisition in astronomy would start with the development of a similar set of initial concepts by children regardless of whether they grew up in the United States or in Greece. We assumed that these concepts would consist of the belief that the earth is flat, that it does not move, and that it is located in the center of the solar system. Also included should be the belief that gravity operates along an up/down gradient, and that the day/night cycle is caused by the movement of the sun and the moon rather than by the movement of the earth. An outline of the expected initial concepts regarding the earth's shape, gravity, movement, and location, and about the day/night cycle, is presented in Table 1.

[Insert Table 1 about here.]

Some support for the view that children conceptualize the earth as flat and gravity as operating in an up/down fashion comes from research by Nussbaum and Novak (1976) and Sneider and Pulos (1983) with American children, by Nussbaum (1979) with Israeli children, and by Mali and Howe (1979) with

children from Nepal. We do not know of any research investigating children's ideas about the earth's movement and location and about the day/night cycle, but our hypotheses about these constructs are consistent with what is known about other constructs.

Children in Greece and in the United States receive similar instruction regarding the shape, gravity, movement, and location of the earth. They learn that the earth is a sphere that rotates around its axis and revolves around the sun; that gravity operates toward the center of the spherical earth; that the day/night cycle is caused by the earth's rotation around its axis rather than by the movement of the sun and the moon; and that the sun and not the earth is located in the center of the solar system (see Table 1).

If we are right in our assumptions that children share common conceptual processes and that initial concepts about the earth are universal, then we should expect that the process of changing these concepts as children are exposed to similar scientific explanations should also be universal. Consequently, the assimilatory concepts which we have observed in American children (Vosniadou & Brewer, 1989) should also be present in Greek children.

Method

Subjects

The American sample consisted of 60 children: 20 children who attended first grade (mean age 6 years and 9 months), 20 children who attended third grade (mean age 9 years and 9 months), and 20 children who attended fifth grade (mean age 11 years). The children came from predominately middle-class backgrounds and attended school in a town in the midwestern United States.

The Greek sample consisted of 90 children: 30 attended kindergarten (mean age 5 years and 5 months), 30 attended third grade (mean age 8 years and 5 months), and 30 attended sixth grade (mean age 11 years and 9 months). They also came from predominately middle-class backgrounds and attended school in a large city in the north of Greece.

Questionnaire

We examined children's knowledge of astronomy using a questionnaire that included questions about the earth's shape and gravity; about the location and movement of the earth, the sun, and the moon; and about the phenomenon of the day/night cycle. The questionnaire was developed through extensive pilot work. To obtain as much information as possible about children's underlying concepts rather than about the information they may have memorized in a superficial way, we developed a methodology that differentiated factual questions from generative questions.

Factual questions were designed to test children's exposure to certain theoretically important facts. An example of this type of question is "What is the shape of the earth?" Children could answer this question correctly by simply repeating information they had obtained from adults without having necessarily incorporated this information into their conceptual framework.

Generative questions were questions to which the children had not been previously exposed and which had the potential of uncovering children's generative concepts. Examples of this type of question are "If you were to walk for many days would you ever reach the edge of the earth?" and "Is there an edge to the earth?" We hypothesized that children would use their conceptual knowledge to create a mental model of the earth and then use this model to derive the answers to our questions. We assumed that children's responses to our generative questions would reflect more accurately their conceptual knowledge because they were not simply repeating facts taught by an adult. Furthermore, we assumed that the presence or absence of agreement between children's responses to our factual and generative

questions could be used to derive information about the extent to which the children had assimilated the scientific information to which they may have been exposed into their underlying conceptual structures.

Procedure

The children were seen individually in interviews that lasted from 30 to 45 minutes. Follow-up questions and confrontation questions were used throughout the interview or at the end of the interview to clarify ambiguous responses and to obtain as accurate a picture of children's responses as possible. Here is an example of the questioning procedure we followed.

Renae (1st Grade)

E: If you walked and walked for many days in a straight line, where would you end up?
C: You'd end up . . .
E: Where?
C: You'd end up somewhere, where you lost yourself.
E: What if you kept on walking?
C: If you turned around you'd be lost.
E: Would you ever reach the end of the earth?
C: Yes.
E: Could you fall off the edge of the earth?
C: No.
E: Why not?
C: Because once you fall off, you can't get back on.
E: Well, would you ever fall off though?
C: No.
E: But there is an edge of the earth?
C: Yes.
E: What if you could get back on, do you think you could fall off then?
C: Yes . . . and if you took the edge of the thing, and you had one hand on it, you could fall off easier.

The questionnaire was originally developed in the United States as part of a larger project on knowledge acquisition in astronomy (Vosniadou & Brewer, 1987) and was first administered to the American children. It was translated by the first author, who is a native speaker of Greek, and was administered to the Greek children with a few modifications, such as the addition of styrofoam models to investigate the earth shape concept.

Results

Earth Shape

Table 2 presents the American and Greek children's responses to the factual question "What is the shape of the earth?" As can be seen, the same kinds of verbal responses were obtained by both groups of children but with a different distribution. "Round" was the preferred response by the younger children in the Greek sample (60% for the kindergarten and 86.6% for third-grade children) and the older children in the American sample (85% and 90% for the third and fifth grade, respectively). The Greek sixth graders preferred the term "sphere" (43.3%), which was not used much by the American fifth-grade children (only 5%). The majority of the first-grade children in the American sample said that the earth's shape is a "circle" (70%), a response not nearly as common in the Greek sample (3.3%). Finally, some of the kindergarten children in the Greek sample (13.3%) said that the earth is shaped like a "triangle," "a square," or just "flat," revealing the presence of an initial, naive concept. This type

of verbal response was not present in the American first-grade children (although it is present in our studies of American preschoolers), except for one child who did not respond to this question but who later drew a rectangle to indicate the shape of the earth.

[Insert Table 2 about here.]

The differences in the responses of the Greek and American children to this question most likely represent subtle variations in lexical usage and do not reflect more fundamental differences in underlying beliefs. In both samples, all of the older children and most of the younger children drew a circle to indicate the shape of the earth when asked to do so (Table 3).

[Insert Table 3 about here.]

Children's seemingly sophisticated responses to these two factual questions did not, however, provide an accurate reflection of their earth shape concept. The difficulties the children in both samples experienced with the earth shape concept became apparent in their responses to the generative question "Is there an edge to the earth?" (Table 4). In response to this question, 70% of the American first graders and 86.6% of the Greek kindergarten children said that there is an edge to the earth (whether people could ever reach it or not--Table 4, responses #2 and #3 combined). The number of children who believed that the earth has an edge decreased with age in both samples, but "yes" was still the most common response to this question in the Greek third-grade sample (66.7%) and quite frequent in the American sample (30%).

[Insert Table 4 about here.]

Why do children draw a circle to represent the shape of the earth but then say that the earth has an edge? The discrepancy in children's responses to the factual and generative questions can be explained in a number of ways. One possibility is that children have simply memorized the adult information that the earth is a sphere without connecting it to their existing knowledge structures. Consequently, when it comes to answering new questions, questions to which they have not been previously exposed, they use their initial concept of a flat earth to answer them.

Another possibility, not inconsistent with the previous one, is that children may have formed an assimilatory concept of the earth's shape. It is possible, for example, that children conceptualize the earth to be round like a disc or like a truncated sphere. In this case, the earth would still be "round" but it would also have an edge. Some support for this hypothesis comes from the responses the children gave us when we asked them to draw a picture of the earth and to show where a man would end up if he travelled in a straight line on the earth. Many children drew a picture of the man reaching the end of the circle and then falling down. Figure 1 shows some of the drawings we obtained from the American third graders in response to this question.

[Insert Figure 1 about here.]

These responses are consistent with the interpretation that at least some of the children think that the earth is round but also flat like a disc, or like a truncated sphere. Further support for this hypothesis can be obtained from the Greek children's selections of a styrofoam model to represent the earth (these styrofoam models were not used with the American children in this study). In this item, the children had to select one out of seven styrofoam models (a square, a rectangle, a triangle, a truncated sphere, a disc, a sphere, and a cone) to represent the earth. With the exception of the cone, which was used as a control item, all the other models represented possible models of the earth's shape. The results from this question appear in Table 5.

[Insert Table 5 about here.]

As can be seen, 13.3% of the kindergarten children selected some kind of linear flat model (triangle, square, rectangle) and 16.7% selected a circular flat model (disc or truncated sphere). A few of the older children also selected the disc or the truncated sphere as a model of the earth. As expected, none of the children picked up the cone as a model of the earth, a finding that shows the children's selections were not random but reflected their beliefs regarding the shape of the earth. These selections demonstrate that Greek children form initial (i.e., linearly flat) or assimilatory (disc or truncated sphere) concepts of the earth's shape that are similar to those obtained from American children (Vosniadou & Brewer, 1989).

Information about the assimilatory concepts the American children had formed comes from their responses to a question in which the children were shown the picture of a farm house in the middle of what appeared to be flat earth and were asked "How come here the earth is flat but before you made it round?" (This question was not given to the Greek children, who were asked to select a model instead.) Children's responses to this question revealed several other misconceptions regarding the earth's shape. As Table 6 shows, in addition to the disc model (response #5), some of the American children had a dual-earth concept (response #8). These children believed that there are two earths: a flat one on which we live, and a round one that is up in the sky. Some other children had an inside-the-sphere concept according to which the earth is round like a sphere but people live on flat ground inside the earth. This was a common response in the American data but did not appear in the Greek data (response #6).

[Insert Table 6 about here.]

Here is an example from the inside-the-sphere assimilatory concept.

Veronica (3rd Grade)

E: How come here the earth is flat but before you made it round?
C: Because you are on the ground but . . . if you go out of earth and go into space you'll see a circle or round.
E: So what is the real shape of the earth?
C: Round.
E: Why does it look flat?
C: Because you are inside the earth.
E: If you walked and walked for many days in a straight line, where would you end up?
C: Somewhere in the desert.
E: What if you kept walking?
C: You can go to states and cities.
E: What if you kept on walking?
C: No response.
E: Would you ever reach the edge of the earth?
C: No. You would have to be in a spaceship if you're going to go to the end of the earth.
E: Is there an edge to the earth?
C: No. Only if you go up.
E: Does anyone live here on the bottom of the Earth?
C: No, because they live in the states up here.
E: But could they live down here?
C: Yes.
E: Why wouldn't they fall off?
C: Because they are inside the Earth?
E: What do you mean inside?
C: They don't fall, they have sidewalks, things down like on the bottom.
E: Is it round like a ball or round like a thick pancake?
C: Round like a ball.

E: When you say that they live inside the earth, do you mean they live inside the ball?
C: Inside the ball. In the middle of it.

Finally, some of the American children simply said that the earth is round, but that people live on flat pieces of land on the earth (response # 9), or on flat pieces of ground on the top part of the earth (response # 7). The remaining children appeared not to recognize the flat/round conflict or to be unable to provide an adequate explanation.

Overall, the results of this cross-cultural comparison suggest that both the American and the Greek children start with the same set of initial concepts and that they are also similar in at least some of the assimilatory concepts they form (e.g., the view that the earth is round like a disc or like a truncated sphere).

Gravity

Children's gravity concept was investigated by asking two key questions, both in response to a drawing that showed a figure standing upside down at the bottom part of the earth (i.e., a circle that was meant to represent the earth). In the first question, the children were asked "Can this man live here at the bottom of the earth?" The responses to this question appear in Table 7. Most of the kindergarten children and quite a few of the older children in both samples said that the man would fall. This response is consistent with the hypothesis that children start by forming a naive concept of gravity according to which things fall in a downward direction, and that people cannot live at the bottom of a spherical earth because they will fall down.

[Insert Table 7 about here.]

The second gravity question was asked with respect to a ball that the man at the bottom of the earth held in his hands: "If this person had a ball in his hand and dropped it, where would the ball go?" As shown in Table 8, most of the Greek kindergartners and the American first graders thought that the ball would fall in the direction opposite to the center of the earth. This response was also shared by most of the Greek third-grade children (73.3%) and a good percentage of the American third graders (40%), as well as by many of the older children in both samples.

[Insert Table 8 about here.]

As in the case of the earth shape concept, it is interesting to observe the discrepancy in children's responses to the two questions that investigated the same concept. Notice that only 30% of the American and 55.2% of the Greek third-grade children gave responses consistent with an up/down gravity concept when asked the gravity question with respect to the man (i.e., they said that the man would fall down). However, 40% of the American and 73.3% of the Greek third graders responded in ways consistent with an up/down gravity concept when the question was asked about the ball (i.e., they said that the ball would fall down, away from the earth). It is possible that some of the children who said that the man would not fall repeated information they had heard from adults without incorporating this information into their existing conceptual framework. These children then reverted to their initial up/down gravity concept when they had to draw inferences about the fall of balls. Others may have formed an assimilatory concept according to which gravity is something that applies to people but not to balls.

Again, these responses are consistent with the hypothesis that the children in both samples will form both similar initial concepts and similar assimilatory concepts.

The Movement of the Earth and the Sun

Table 9 presents children's responses to the question "Does the earth move?" As in the case of gravity, we find that in both samples there is a clear developmental shift from the predicted initial concept of a stationary earth to the currently accepted view that the earth rotates around its axis and revolves around the sun. Both the Greek and the American children showed some evidence of forming similar assimilatory concepts as well. For example, there were some children who believed that the earth revolves around the moon, or that it moves directly toward and away from the sun in a linear type of movement. Finally, it is interesting to note that some of the Greek kindergarten children gave unique responses, not observed in the American children. For example, one child said that the earth moves when the man who holds the earth on his shoulders moves. This response appears to have been influenced by the Greek myth in which Atlas is said to support the earth on his shoulders.

[Insert Table 9 about here.]

The responses to the question "Does the sun move?" appear in Table 10. Again, we observe in both samples a similar developmental shift from the expected initial concept of a sun moving up/down or from east to west to the view that the sun is stationary. Very few children knew that the sun rotates around its axis.

[Insert Table 10 about here.]

Explanations of the Day/Night Cycle

Children's explanations of the day/night cycle were explored by asking three questions: "Where is the sun at day?", "Where is the sun at night?", and "How does this happen?" The children from both samples gave very similar types of answers to the first question. Most of them said things like, "the sun is up in the sky," or "in the east," or "on our side of the earth." Responses to the second question were more varied and showed some differences between the Greek and American children (see Table 11).

[Insert Table 11 about here.]

The Greek children were more likely to say that the sun is behind the mountains, the clouds, or the sea (response #2), while the American children were more likely to say that the sun is "West" or down, underneath the earth (response #3). This difference could be due to the preponderance of mountains and sea in the Greek terrain and their absence from the flat plains of the American midwest. Some children thought that the sun turns off at night (response #5), or that it goes inside the night or that night comes and covers it (response #6).

Again, the older children's responses were more in agreement with currently accepted scientific views. Most of the American fifth graders and the Greek sixth graders said that the sun is on the other side of the earth (response #8), or that the sun stays where it is (response #7). Some of the children who said that the sun is on the other side of the earth knew that the day/night cycle happens because of the earth's axis rotation. Similarly, some of the children who said that the sun stays where it is also explained its apparent disappearance at night in terms of the earth's axis rotation. Others thought that the sun stays where it is because clouds or the moon block it.

Children's explanations of the day/night cycle become more explicit when they are asked to explain how the day/night cycle happens (Table 12). As expected, most of the younger children provided naive explanations of this phenomenon, based on their everyday experiences. For example, they said that clouds or night cover the sun, or that the sun goes behind the mountains or the clouds, or that the sun goes down, underneath the earth. The Greek kindergartners gave a number of animistic or artificialistic (Piaget, 1929) explanations. These children used words like "the sun hides" or "sleeps" to describe the

disappearance of the sun during the night or said that night happens because people must go to sleep. Non-explanatory responses (e.g., it is light during the day and dark during the night) were also used by these children. Although these responses were not found in the first-grade American data, we have obtained similar types of responses from American preschool children in other studies (Vosniadou & Brewer, in preparation).

[Insert Table 12 about here.]

Very few children, even among the fifth and sixth graders, stated that the day/night cycle is caused by the earth's axis rotation. Some children thought that the day/night cycle is caused by the earth's revolution around the sun, or mentioned both movements of the earth. Many children knew that the day/night cycle has to do with the movement of the earth but could not explain how. These types of responses were common in both samples.

Some responses revealed interesting assimilatory conceptions. For instance, some children believed that the day/night cycle is caused because the sun revolves around the earth; others said that the earth rotates around its axis and also that the sun moves up and down. Finally, some children thought that the moon is located in some part of the sky where it is always night and that the earth's axis rotation causes the day/night cycle because it makes our side of the earth face the moon.

The Location of the Earth, Sun, and Moon in the Solar System

In these questions the children were shown a picture of the solar system and were asked to point to the earth, the sun, and the moon. Originally, we included these questions in the Greek questionnaire, not the American one. At a later date, these questions were included in a modified questionnaire administered to a new sample of 45 American children of comparable ages (16 first graders, 15 third graders, and 16 fifth graders) and social class, attending school in the same town as the American children in our first sample. We present these data here to complete our cross-cultural comparison. A large percentage of the Greek kindergarten children (40%) were not asked these questions because they could not identify the picture of the solar system. Children's responses to the question "Where is the earth?" showed the expected shift from a geocentric to a heliocentric concept (see Table 13). As can be seen, most of the younger children pointed to the sun instead of to the earth or to another planet. The older children gave few geocentric responses but still many of them, particularly the Greek children, could not distinguish the earth from the other planets.

[Insert Table 13 about here.]

Responses to the instruction "Point to the sun" (Table 14) showed again the expected developmental shift from a geocentric to a heliocentric concept (i.e., from thinking that the sun is in the place of a planet to placing it in the center of the solar system). Finally, responses to the instruction, "Point to the moon" showed that most of the younger children could not identify the moon, and that even quite a few of the older children thought that the moon is a planet (Table 15).

[Insert Tables 14 & 15 about here.]

Discussion

The results presented in this report support the hypothesis that children form initial concepts of the world around them in much the same way that they seem to extract certain phenomenological principles or to construct intuitive theories of the behavior of physical objects (diSessa, 1982; McCloskey, 1983). These concepts appear to be independent of the particular culture in which the children grow up. In both the Greek and American samples, the younger children conceptualized the earth to be flat rather than spherical; thought that things fall in a downward direction rather than toward the center of the

spherical earth; said that the earth does not move but that the sun and moon do; explained the day/night cycle on the basis of the movement or blocking of the sun and the moon; and thought that the earth is located in the center of the solar system.

Not only were the Greek and the American children similar in the kinds of initial concepts they constructed, they also seemed to go through similar steps in the process of restructuring them. The results presented in this report are consistent with the view that children go through different levels of understanding a scientific concept when it contradicts an initial concept based on phenomenal experience.

One, rather superficial level of understanding characterized the children who appeared to simply memorize the adult teachings to which they were exposed without connecting them to their initial concepts. These children answered the equivalent of our factual questions correctly. In other words, they said that the earth is round (or a circle), that it moves, that people at the bottom of the earth will not fall down, etc. These children did not, however, use the scientific concepts when they answered new questions, questions to which they had not been previously exposed. Consequently, these children said that the earth has an edge, or that the ball held by a man standing at the bottom of the earth will fall down, away from the earth. The independent co-existence of both an initial and a scientific concept seemed to also be present in the case of the children who said that the earth rotates about its axis but explained the day/night cycle on the basis of the movement of the sun and the moon.

A second level of understanding was revealed in the answers of the children who seemed aware of the fact that there can be two contradictory explanations of the same phenomenon. Some children in our sample attempted to resolve these contradictions by assimilating the scientific explanations to their existing conceptual structures. This assimilatory mechanism gave rise to various misconceptions, such as those encountered in the case of the earth shape concept. As was discussed in the results section, many children seemed to interpret the information that the earth is a sphere to mean that the earth is circular but flat (like a disc); or that we live on flat ground inside the spherical earth; or that there are two earths--a flat earth on which we live and a spherical earth that is up in the sky. These misconceptions demonstrate children's difficulties in understanding the concept of a spherical earth and reveal their attempts to assimilate the information that the earth is a sphere to their initial concept of a flat earth.

One could conceptualize the genesis of misconceptions in the following way. When children who have an initial concept of a flat and stationary earth learn from an adult (parent, teacher, or author of a book) that the earth is round, they are confused. They do not want to think that this information is wrong, yet they cannot reconcile it with their experience of a flat earth. In an attempt to solve the contradiction between their phenomenal experience and the information they receive from adults, children interpret the culturally accepted model in a way that reconciles it with their intuitive experience. As a result, they create an assimilatory concept, such as the "two earth" concept, or the "inside-the-earth" concept or the "disc earth" concept. What all of these assimilatory concepts have in common is the attempt to reconcile the information that the earth is round with the initial concept of a fundamentally flat earth.

Finally, a third level of understanding of the adult/scientific concepts seems to have been achieved by the children who could use these concepts in a generative way. The generative use of scientific concepts does not necessarily imply that the initial concepts have been extinguished. The two concepts may still co-exist, but unlike the initial level of understanding, the person is aware of their simultaneous existence and can make consistent use of them as the situation and/or need dictates.

Overall, the similarities in the responses of the American and the Greek children in our sample were striking. Some differences were, of course, found and these differences appeared to be of three kinds. First, there were differences that had to do with time of acquisition of the culturally accepted concepts. In general, the kindergarten and third-grade children from Greece gave slightly less sophisticated

responses than the first- and third-grade American children, a difference that could be related to differences in age (the Greek children were about a year younger than their American counterparts) or differences at the onset of instruction. The third-grade American children had a unit on astronomy right before we started testing them, whereas the third-grade Greek children did not. The responses of the Greek sixth-grade children varied. In some cases they were more advanced than the responses of the American fifth graders, and in some cases they were not; again these differences could be related to differences in instruction.

Second, there were differences in initial concepts that appeared to be related to differences in the physical environment between the two countries. For example, the prevalance of mountains and sea in the Greek landscape seem related to the fact that the Greek children preferred to explain the day/night cycle in terms of the disappearance of the sun behind the mountains or the sea, while the American children preferred the explanation that the sun goes down underneath the earth.

Finally, certain aspects of the data raise the possibility of unique culture-specific types of influences, both on children's initial and their assimilatory concepts. For example, exposure to the Greek mythology in the Greek sample may be related to the frequency of the animistic explanations we received from these children as well as to the occurrence of specific types of responses, such as the view that the earth is supported on the shoulders of a man and moves when this man moves. While we do not have any direct evidence of the influence of culture-specific cosmological beliefs on children's assimilatory conceptions, there is some indirect evidence. Some assimilatory concepts were more prevalent in one sample than the other. For example, the "inside-the-sphere" assimilatory concept was a powerful one in our American data but did not appear in the Greek data. It is not clear at this point if this is a real cultural difference. We are in the process of testing more Greek and American children with a more detailed questionnaire and hope to have the answer to this question in the future. It is interesting to note, however, that some cross-cultural differences in assimilatory concepts have been observed in other cross-cultural studies we have conducted. These studies have shown, for example, that children from India favor the view that the earth is like a flat disc floating on water (Samarapungavan & Vosniadou, in preparation), while a number of children from Samoa form "ring earths" when asked to produce a model of the earth using clay (Brewer, Herdrich, & Vosniadou, 1988). These children roll the clay into a long rope and then wrap it around to form a ring. Responses such as these are very rare in both the American and the Greek samples and could be interpreted as demonstrations of culture-specific influences on children's assimilatory models. Apparently, the view that the earth floats on water is a dominant one in Indian cosmology, while there is evidence suggesting that in Samoa physical and social space is organized in the form of a ring. For instance, the houses in a Samoan village are arranged in the form of a circle around an open court. (See Brewer, Herdrich, & Vosniadou, 1988, for a more detailed discussion of this issue.)

To summarize, the results of this study showed that the children in both samples constructed similar initial concepts regarding the earth's shape, movement and gravity, and about the day/night cycle. The Greek and American children also appeared to go through a similar process of restructuring these concepts to make them more consistent with current scientifically accepted views. As a result, they also formed similar assimilatory concepts or misconceptions. Differences regarding the onset of instruction, the physical environment, and certain culture-specific cosmological beliefs appear to have influenced the children's conceptual framework in a number of specific instances.

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Table 1

Expected Responses for Initial and Scientific Concepts Regarding the Earth's Shape, Gravity, Movement, Size, and Location and the Phenomenon of the Day/Night Cycle

	Initial Concepts	Scientific Concepts
Earth's shape	Flat	Sphere
Earth's gravity	Things fall down	Things fall toward the center of the earth.
Earth's movement	Stationary	Axis rotation and revolution around the sun.
Earth's location	Earth is in the center of our solar system	The sun is in the center of our solar system. The earth is a planet revolving around the sun.
Day/night cycle	Movement of the sun and moon	Movement of the earth.

Table 2

Percent Responses to the Question, "What is the shape of the earth?"

Responses	American Children Grade 1	American Children Grade 3	American Children Grade 5	Greek Children Grade K	Greek Children Grade 3	Greek Children Grade 6
1. Do not know/No response	5	0	0	16.7	0	0
2. Triangle, square, rectangle, or straight	0	0	0	13.3	0	0
3. Circle	70	10	0	3.3	6.7	16.7
4. Oval	0	0	5	6.7	0	20.0
5. Round	10	85	90	60.0	86.6	20.0
6. Sphere, round like a ball	15	5	5	0	6.7	43.3

Table 3

Percent Responses to the Question, "Can you draw a picture of the earth?"

	American Children		
	Grade		
Responses	1	3	5
1. Rectangle	5	0	0
2. Straight line but changes to circle after questioning	10	0	0
3. Circle within square frame	5	0	0
4. Circle	80	100	100

	Greek Children		
	Grade		
Responses	K	3	6
1. Triangle or straight line	16.7	0	0
2. Circle with flat line underneath it	3.3	0	0
3. Circle	80	100	100

Table 4

Percent Responses to the Question, "Is there an edge to the earth?"

	American Children			Greek Children		
	Grade			Grade		
Responses	1	3	5	K	3	6
1. Do not know/No response	0	0	0	6.7	3.3	0
2. Yes	60	20	0	73.3	63.4	10
3. Yes, but we can't reach it (because it is too far away, because there is an ocean or mountains, because we are inside the earth, etc.)	10	10	10	13.3	3.3	0
4. No	30	70	90	6.7	30.0	90

Table 5

Percent Responses to the Question, "Which one of these models looks more like the earth?"

	Greek Children		
		Grade	
Responses	K	3	6
1. Triangle, rectangle, square	13.3	0	0
2. Truncated sphere, disk	16.7	6.7	6.7
3. Sphere	70	93.3	93.3

Table 6

Frequency of American Children's Responses to the Question, "How come here the earth is flat but before you made it round?"

Responses	Grade 1	Grade 3	Grade 5
1. Not applicable (child thinks the earth is flat)	1	0	0
2. Don't know/ no response	1	0	0
3. Changed from round earth to flat earth	1	0	0
4. Child appears not to recognize the conflict	2	0	0
5. The earth is round like a disc or a truncated sphere	1	3	0
6. The earth is round on the outside but inside it is flat	3	5	6
7. The earth is round but we live on flat piece(s) on the top	0	1	0
8. There are two earths (one is round & the other is flat)	2	2	0
9. The earth is round but we live on flat pieces of land	1	0	2
10. Child insists that the earth is round, recognizes conflict but cannot explain it adequately	5	6	9
11. Child gives an adequate explanation	2	3	2
12. Other	1	0	1

Table 7

Percent Responses to the Question "Can this man live here at the bottom of the earth?"

	American Children			Greek Children		
		Grade			Grade	
Responses	1	3	5	K	3	6
1. Do not know/No response	20	0	5	20	0	3.3
2. Yes or No but he will fall	55	30	20	66.7	55.2	20.0
3. Yes or No, but he will not fall	25	70	75	13.3	44.8	76.7

Table 8

Percent Responses to the Question, "If this person had a ball in his hand and dropped it, where would the ball go?"

	American Children			Greek Children		
		Grade			Grade	
Responses	1	3	5	K	3	6
1. Do not know/No response	0	0	0	16.7	0	0
2. Away from the earth	80	40	45	76.6	73.3	23.3
3. Toward the earth	20	60	55	6.7	26.7	76.7

Table 9

Percent Responses to the Question, "Does the earth move?"

Responses	American Children Grade 1	American Children Grade 3	American Children Grade 5	Greek Children Grade K	Greek Children Grade 3	Greek Children Grade 6
1. Do not know/No response	5	0	0	0	0	0
2. No	25	20	0	46.7	6.6	0
3. Yes, motion unspecified	40	55	40	33.3	76.7	80
4. Yes, axis rotation	10	20	15	0	0	3.3
5. Revolution	0	5	15	0	16.7	0
6. Both axis rotation and revolution	0	0	30	0	0	13.4
7. Non-rotational movement (earthquake, mythical)	5	0	0	16.7	0	0
8. Assimilatory movement (e.g., revolves around the moon, linear movement of the earth towards the sun, etc.)	15	0	0	3.3	0	3.3

Table 10

Percent Responses to the Question, "Does the sun move?"

Responses	American Children Grade 1	3	5	Greek Children Grade K	3	6
1. Do not know/No response	5	0	0	0	0	0
2. No	30	70	70	60	83.3	90
3. Yes, non-rotational movement (up/down - east/west)	35	10	5	36.7	13.3	10
4. Yes, unspecified	30	10	25	0	0	0
5. Yes, axis rotation	0	5	0	0	3.4	0
6. Other (e.g., in circles, follows people)	0	5	0	3.3	0	0

Table 11

Percent Responses to the Question, "Where is the sun at night?"

	American Children			Greek Children		
		Grade			Grade	
Responses	1	3	5	K	3	6
1. Do not know/No response	0	0	0	3.3	0	10
2. Behind mountains, sea, or clouds	5	10	10	40	36.7	13.3
3. West or down (on the ground, under the earth)	55	10	15	10	10	26.7
4. Sleeps	0	0	0	13.3	3.3	0
5. Turns off	0	0	0	3.3	0	0
6. Naive other (goes away in the night, etc.)	0	0	5	6.7	3.3	0
7. Stays where it is	10	20	30	0	26.7	16.7
8. Other side of earth or world	25	55	35	20	20	33.3
9. In space, universe	5	5	5	3.3	0	0

Table 12

Percent Responses to the Question, "How does this happen?" in Relation to the Day/Night Cycle

Responses	American Children Grade 1	American Children Grade 3	American Children Grade 5	Greek Children Grade K	Greek Children Grade 3	Greek Children Grade 6
1. Do not know/No response	15	0	0	23.3	10	20
2. Naive explanations (clouds or night cover the sun, sun moves behind mountains, clouds, or sea, sun moves west or down underneath the earth, etc.)	55	35	20	33.3	30	6.7
3. God made it that way	5	5	0	3.3	0	0
4. Animistic & artificialistic (night comes so that people can sleep, the sun hides, etc.)	0	0	0	20	0	0
5. Non-explanatory	0	0	0	13.3	6.7	0
6. Assimilatory (e.g., the sun revolves around the earth, the earth rotates & stops for a while, the earth rotates & the sun moves up/down, the earth revolves around the moon)	5	5	0	3.3	10	6.7

Table 12 (Continued)

Responses	American Children Grade 1	3	5	Greek Children Grade K	3	6
7. Correct (the earth rotates around its axis)	10	25	35	0	13.3	16.7
8. The earth moves unspecified	0	15	10	0	10	26.7
9. The earth revolves around the sun	0	10	10	3.3	16.7	13.3
10. Mentions both movements of the earth	10	0	15	0	3.3	10
11. Other	0	5	5	0	0	0
12. Missing	0	0	5	0	0	0

Table 13

Percent Responses to the Instruction, "Point to the earth" in a Picture of the Solar System

Responses	American Children			Greek Children		
	Grade			Grade		
	1	3	5	K	3	6
1. Do not know/No response	6	0	0	10	0	3.3
2. Points to sun	69	20	12	33.3	46.7	10
3. Points to earth	13	46	75	0	3.3	20
4. Points to another planet	0	34	13	10	43.3	56.7
5. Shows area between two planets or other uninterpretable responses	12	0	0	3.3	6.7	10
6. The question was not asked because the child did not recognize the picture of the solar system	0	0	0	40	0	0
7. Missing	0	0	0	3.3	0	0

Table 14

Percent Responses to the Instruction, "Point to the sun" in a Picture of the Solar System

Responses	American Children Grade 1	3	5	Greek Children Grade K	3	6
1. Do not know/No response	13	0	6	6.7	6.7	0
2. Center (correct)	25	73	88	6.7	53.3	86.7
3. A planet	50	20	6	23.3	23.3	13.3
4. Shows area between two planets, or nonsensical response, or not here	12	7	0	16.7	16.7	0
5. Not applicable	0	0	0	43.3	0	0
6. Missing	0	0	0	3.3	0	0

Table 15

Percent Responses to the Instruction, "Point to the moon" in a Picture of the Solar System

	American Children			Greek Children		
		Grade			Grade	
Responses	1	3	5	K	3	6
1. Do not know/No response	31	33	31	13.3	13.3	3.3
2. Correct	0	27	50	3.3	26.7	43.3
3. A planet	63	40	19	10	43.3	36.7
4. Other	6	0	0	30	16.7	16.7
5. Not applicable	0	0	0	40	0	0
6. Missing	0	0	0	3.4	0	0

Figure Caption

Figure 1. Selected Responses by American Third-Grade Subjects to the Question, "Draw a picture of the earth and show me how a man would travel on a straight line and where he would end up."

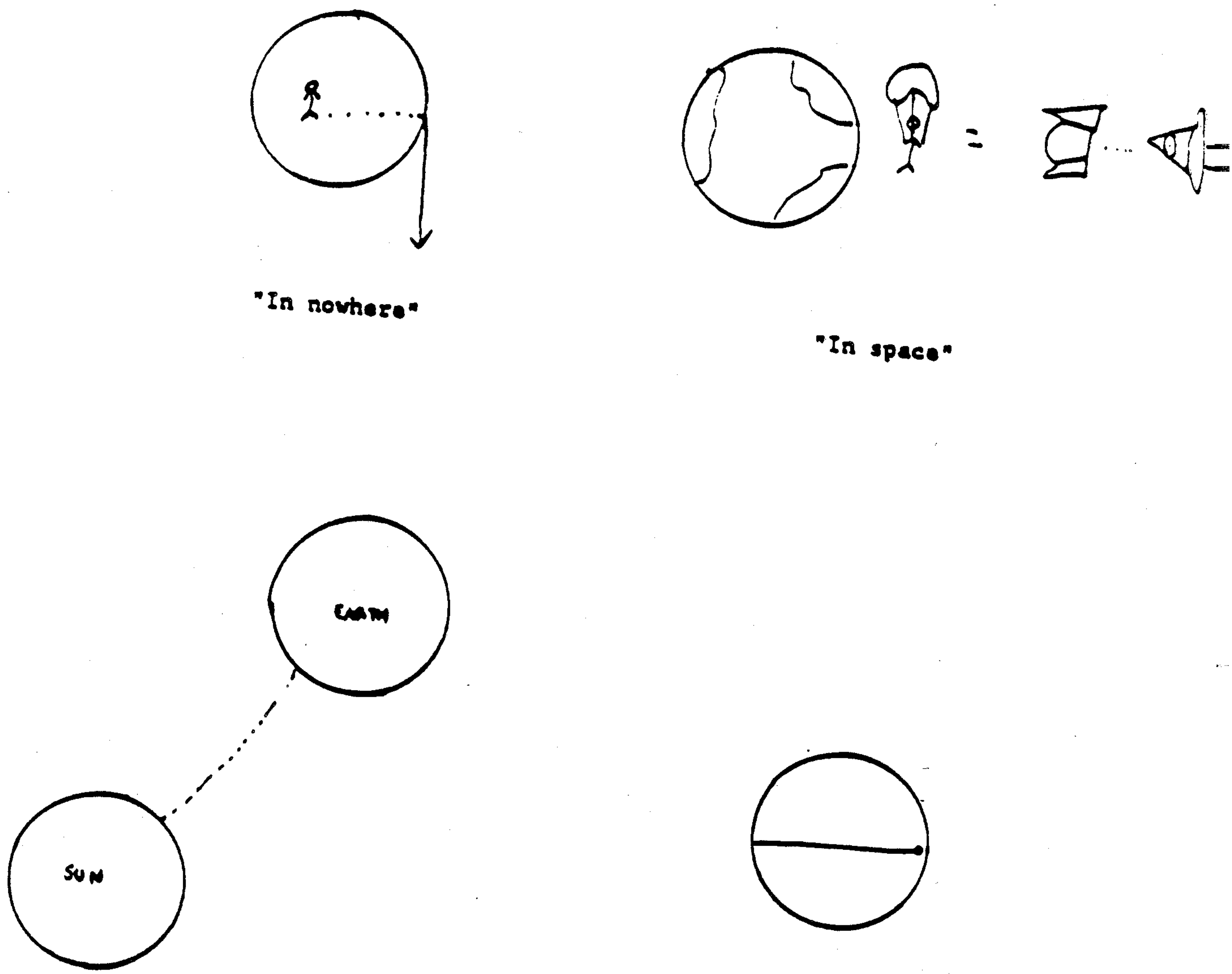

Figure 1